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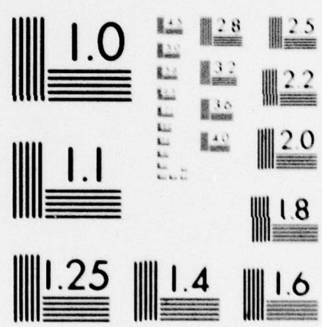

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CEILING FANS FOR ENERGY CONSERVATION

GEORGE T. STORY

15 May 1979

Final Report

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Prepared for
US Army Facilities Engineering Support Agency
Technology Support Division
Fort Belvoir, VA 22060

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Considerations for the use of ceiling fans to conserve energy are given. A sample calculation of energy savings is included.

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CEILING FANS FOR ENERGY CONSERVATION

Ceiling fans can provide energy savings in high ceilinged buildings where warm air accumulates and causes excess heat loss through the upper parts of the building envelope. It is not possible to predict with certainty when and to what extent this phenomena will occur. In general though, thermal stratification of the air in buildings can occur in high ceilinged structures (over 15') where the heating system is not combined with an air distribution system to promote vertical mixing of the air. It is prevalent in warehouses and maintenance shops where unit heaters are located at the ceiling level and discharge to the side rather than down. It also appears where radiators are used to heat high ceilinged structures.

In order to predict the savings from the destratification of a particular structure, it is necessary to measure the floor to ceiling temperature distribution during a heating period. When this is known, an assumption can be made to describe the thermal profile after installation of fans and a savings estimate can be made from standard heat transfer calculations. The following example will serve as a guide to making these calculations:

Assume a maintenance shop 250' by 150' with a 25' ceiling. The temperature distribution is measured as follows:

Floor level - 69°F

5' - 72°F

10' - 79°F

15' - 86°F

20' - 87°F

25' - 87°F

It can be seen that the area above the worker level is being unnecessarily heated. Assume that through the use of ceiling fans, this heat can be redistributed downward and that the temperature distribution could be altered to be:

Floor level - 69°F

5' - 72°F

10' - 73°F

15' - 75°F

20' - 75°F

25' - 76°F

These are typical examples of before and after fan temperature distributions. Now, the difference in heat transfer through the upper parts of the structure can be calculated.

The roof on the shop is 1" of wood with 2" of insulation with bitumen roofing on top. We calculate the heat transmission coefficient of the roof as follows: (see ASHRAE handbooks)

LAYER	R VALUE	$\frac{FT^2\ HR\ ^oF}{BTU}$
Inside Air	0.61	
Wood	0.93	
Insulation	5.56	
Bitumen	0.33	
Outside Air	0.17	
Total	7.60	

Roof U value = 1/R = 0.13 $\frac{BTU}{FT^2\ HR\ ^oF}$

The walls of the structure are 8" concrete block

LAYER	R VALUE $\frac{F^2\ HR\ ^oF}{BTU}$
Inside Air Layer	0.68
8" Block	1.72
Outside Air Layer	0.17
	2.57

$$\text{Wall U Value} = \frac{1}{2.57} = 0.39 \frac{BTU}{FT^2\ HR\ ^oF}$$

There is a row of windows around the shop. They are 6' tall and reach from the 14' level to the 20' level (no storms).

The effective U value of single pane windows (metal sash, 80% glass) is

$$1.00 \frac{BTU}{HR\ FT^2\ ^oF}$$

Air infiltration through the windows is calculated as follows:

Assume an outside windspeed (winter) of 10 mph. Theoretical pressure drop across the windows is given by:

$$P_v = 0.000482\ V_w^{\ 2}$$

where

P_v = velocity head, inches of H_2O

V_w = wind velocity, mph

so

P_v = .048 inches of H_2O

Effective pressure differences requires a factor of 0.64 to account for build up of pressure inside a building, so:

$$P = 0.64\ (.048) = 0.031 \text{ inches of } H_2O$$

Infiltration can be determined from the following functions[1] for these given types of windows:

(1) Loose fit w/o weather strip

(2a) Average fit w/o weather strip

(2b) Loose fit with weather strip

(3) Average fit with weather strip

Infiltration Functions:

(1) $I = 40 + 370\ P$

(2) $I = 14 + 132.5\ P$

(3) $I = 7 + 70\ P$

where I = Cubic Feet per Hour (CFH) per foot of crack

The value is then reduced by half to account for exiting air.

So in this example (assuming average fit)

$P = .031$

$I = 14 + 132.5\ (.031)$ CFH per foot of crack

$$I = 18 \quad \frac{\text{CFH}}{\text{Ft of crack}}$$

The windows are 1 sq ft panes so we have 10,400 ft of crack or

I = 187,200 CFH

The amount is divided in half to account for exiting air so:

I = 93,600 CFH

---

[1] Retrofitting Existing Housing for Energy Conservation: An Economic Analysis - US Department of Commerce and Federal Energy Administration, Dec 1974

We are now in a position to calculate the difference in heat loss for the two different temperature distributions.

The temperature difference across the roof has been reduced by $11^{\circ}F$ so the difference in heat transfer through the roof is:

$$Q = UA \triangle T = 0.13 \times 150 \times 250 \times 11$$

$$= 53{,}625 \text{ BTU/HR}$$

For the section of wall from 10' to 14' (we will ignore the area below this for conservatism) we have reduced the temperature by about $8^{\circ}F$, so,

$$Q = UA \triangle T = (0.39)\ (3200 \text{ ft sq})\ (8)$$

$$= 9{,}984 \text{ BTU/HR}$$

For the windows (14' to 20') an $11^{\circ}F$ drop, so

$$Q = UA \triangle T = (1.00)\ (4800)\ (11) = 52{,}800 \text{ BTU/HR}$$

For the wall section above the windows:

$$Q = UA \triangle T = (0.29)\ (4000)\ (11)$$

$$= 17{,}160 \text{ BTU/HR}$$

The difference in heat loss from air infiltration is calculated as follows:

$$Q = 0.018 \frac{\text{BTU}}{\text{HR-CFH}} \times \text{CFM} \times \triangle T$$

$$= (0.018) \times (93{,}600 \text{ CFH}) \times (11)$$

$$= 18{,}533 \text{ BTU/HR}$$

So our total change in heat loss due to the operation of the fans will be:

$$= 152{,}102 \text{ BTU/HR}$$

The annual BTU savings can now be found by multiplying this figure by the number of heating hours per year (assume 2000 for this example).

$$\frac{\text{MBTU Savings}}{\text{YR}} = \frac{152{,}102 \times 2000}{10^6} \quad 300 \ \frac{\text{MBTU}}{\text{YR}}$$

If the building is heated by oil at $.50/gal, and the furnace is 75% efficient, the cost per MBTU is:

$$\frac{\$}{\text{MBTU}} = \frac{.5}{(.75)\ (.1387)} = \$4.80$$

So the yearly dollar savings due to reduce fuel consumption is:

$$\text{Annual savings} = 300 \times 4.80 = \$1{,}440.00$$

A typical 52" fan will destratify about 2500 ft^2 of area in a building with a 25' ceiling. Thus, our example building would require 15 fans. Typical power consumption of a fan is 250 watts so 15 fans would use 3.75 kw. For a 2000 hr. heating season, this means a consumption of 7500 KWH. At $.04/KWH, this yields an annual cost of $300. Thus, the net annual savings are:

$$\$1{,}440 - \$300 = \$1{,}140$$

The installed cost of fans is typically $150 per fan. So for this example, the total cost is $2,250.

This yields a simple payback time of

$$\frac{\$2{,}250}{\$1{,}130/\text{HR}} = 1.97 \text{ years}$$

It can be seen from this example that a rapid payback can be achieved by the application of fans where severe thermal stratification exists.

There are several points that should be considered when placing fans. They should not be located over an area where personnel are working permanently as the drafts can be troublesome. If the fans will be near such an area, it is advisable to equip them with a speed control that can be accessed from the floor level. These are usually available from the fan manufacturer. If heat producing equipment is present, it is beneficial to locate a fan directly over it to help recycle that heat.

There are other devices available to control thermal stratification. One of these is a small fan mounted in a 6" to 12" duct which directs the air to the floor level. Research at the National Bureau of Standards has indicated that these are not as effective as ordinary ceiling fans.

They may however, be more architecturally acceptable in offices, churches, or other more finished buildings. Inclosed fans (appearing similar to unit heaters) are also available. These may be useful for safety purposes if personnel are frequently in the ceiling area. These units are more expensive and therefore have longer payback periods.

The standard type of fans are also available in decorator designs with choices of colors, patterns and fan-light combinations. These are also more costly, however, they may be acceptable in some applications where utility type fans are not.

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